PRODUCTION

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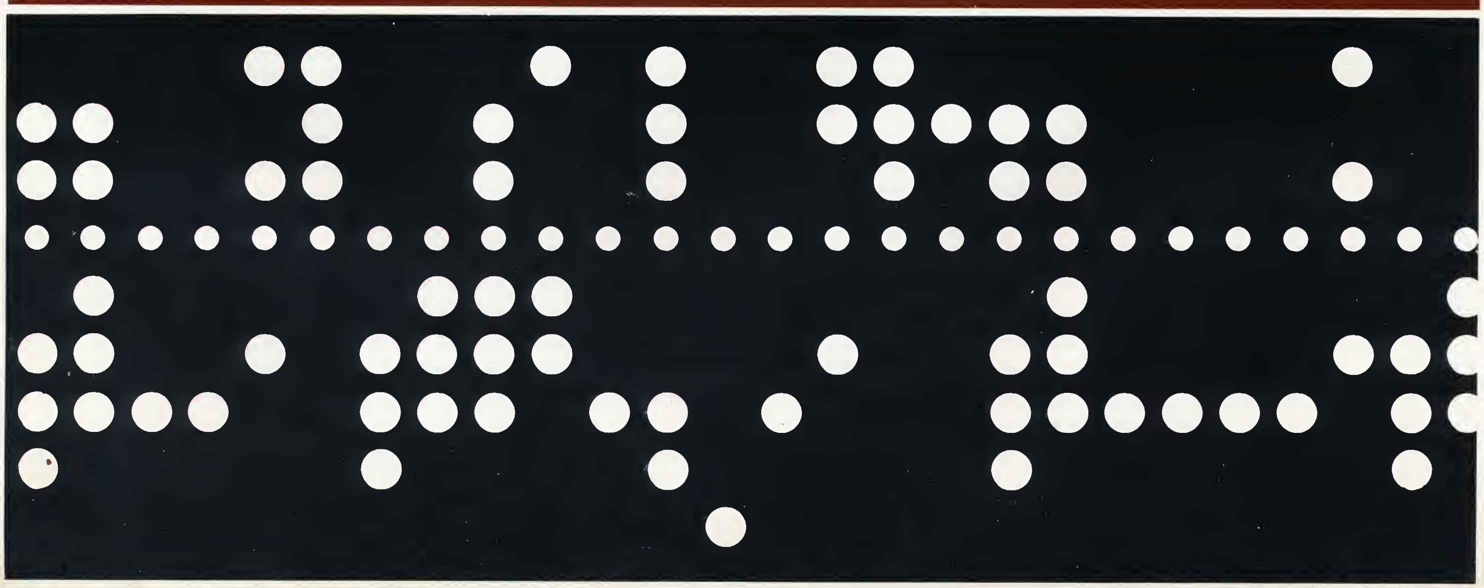
NUMERICAL CONTROL

NUMERICAL CONTROL will be used in every competitive production plant within five years. Proved in production of service parts, prototypes, tooling and dies, it reveals new ways to cut costs and improve profits. Tested in the manufacture of optional parts and special orders, it points the way to increasing flexibility in production lines—and decreasing limitation in product design. It will combine versatility with productivity in machining, forming, inspection, plating, painting, welding, heat treating and materials handling. Its tapes will be used instead of blueprints to streamline communications between customer and vendor, and to assure production to specification. Numerical control is revolutionizing production metalworking.



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The N/C Story in Microcosm

Taking the giant step into numerically controlled processes is an experience still ahead for a majority of metalworking plants. It becomes increasingly obvious, however, that it will eventually be taken. No manufacturing man in a progressive company now can afford to shrug n/c off as a system that "won't work in my plant". If it won't fit today, tomorrow's product requirements or equipment developments may change the circumstances. In one company's experiences, below, are found many, if not most, of the questions that should be asked and satisfactorily answered regarding numerical control.

Albert J. Taylor, Executive Editor

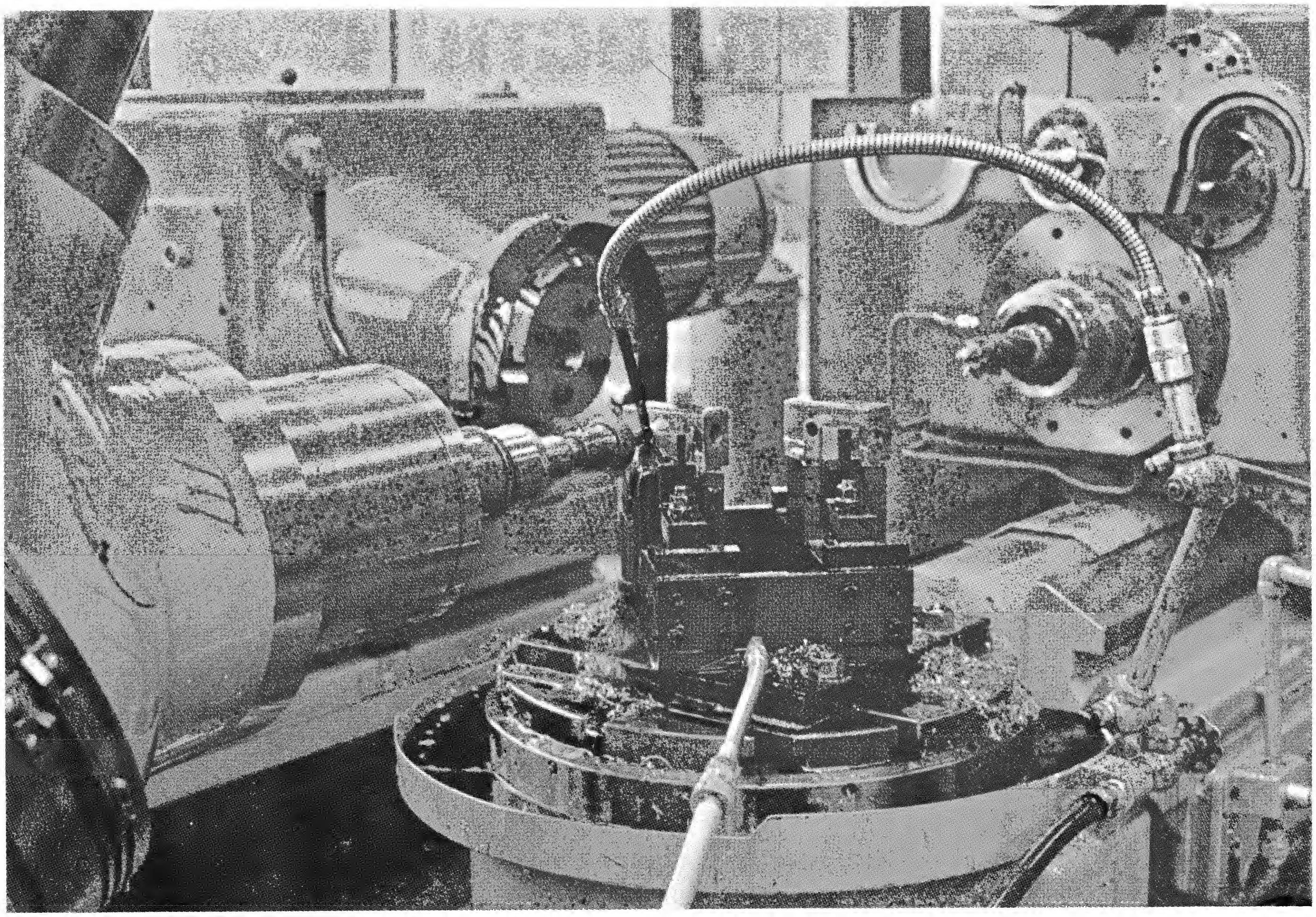
• It's been said with some frequency that when n/c comes in a plant door, the old ways of doing business go out. What is meant is that more than a new kind of hardware for machining is present in an n/c machine; a different approach to processing, fixturing, operating, materials handling, and perhaps assembling may be necessary. Certainly, some new considerations with respect to economic justification procedures (see page 74) have been added.

But these changes do not need to be disruptive. They do, however, need advance planning, more than the usual amount of preliminary work in equipment selection, and an open-eyed awareness that n/c is a different "breed of cat" from the run-of-the-mill machine tool.

A company considering taking its first "plunge" into n/c—and every working day sees several dozen metalworking plants doing just this—faces some serious pitfalls. They're making a substantial investment; they may be changing their whole shop routines; they certainly will be calling upon maintenance men, operators, and process men for skills previously unrequired.

The experiences of any one company probably would not encompass *all* of the factors which each company should examine for itself to determine whether n/c provides the best answer to its kinds of needs. But it is possible, through careful looking, to find some companies which apparently have approached the n/c question in the *right* way, and have made a pro-n/c decision (not without occasional qualms) that is working out to their economic and personal satisfaction.

Such a company is The Aro Corp. of Bryan, O. In step-by-step fashion, its story of looking



The tape-controlled MT-3 machining center combines three self-contained machining heads about an indexing work table which feeds vertically and horizontally. Two of the heads have automatic tool changers.

at n/c, justifying the expenditure, finding the equipment's proper niche in the manufacturing operations, learning some "do's" and "don'ts" with respect to tooling, and selecting personnel, makes an almost "textbook perfect" example of what n/c is all about.

Aro is a medium-sized company with an impressive growth record. It produces a wide range of air-operated products and automated systems for industrial, automotive, and aerospace markets. Its principal industrial products are portable air-powered grinders, drills, screwdrivers, nutsetters, impact wrenches and other air tools; self-feed drilling units and power motors for automation; air hoists, industrial pumps and airless paint spray systems; lubricating equipment, including lube rigs for mobile automotive field service; spray washers and underspray equipment. The company's product base, planned for diversification, has developed soundly. By specializing in products using compressed air, the company has been able to widen its product line and markets while at the same time unifying its manufacturing techniques.

Much time, effort and money is spent at Aro in continuous modernization of internal operations. Capital expenditures for the ten years preceding 1964 ranged from \$420,000 for the lowest year to \$1,381,000 for the highest year. In 1963, for example, capital expenditures of \$978,000 exceeded depreciation by \$248,734. During the ten-year period, the company's net worth, including property, plants, and equipment, increased from about \$5½-million to almost \$12½-million. The completely modern plant at Bryan now occupies about 300,000 sq ft and employs about 1200 persons.

It is not remarkable that such a company, dedicated to modernization and growth and with the cash resources available for expenditures that will increase efficiency and productivity of manufacturing operations, should consider using numerically-controlled equipment. What is noteworthy, however, is the depth to which their studies went, the thoroughness with which they approached the problem of selecting and training of personnel, and their determination to maximize the return on their investment.

A study into the value of n/c equipment

to their operations was started several years ago and was pursued by key personnel in manufacturing and in the manufacturing research and development department with the same thorough and careful preplanning approach that has contributed so much to Aro's competitive success and growth in the past. Preliminary investigations revealed that an n/c machining center would relieve the pressures of rush orders and speed production of short runs without disrupting regular machining processes. The preliminary cost studies looked favorable, and indicated the possibility of substantial over-all cost savings as well as improved manufacturing efficiency.

Stage I—INITIAL INVESTIGATION

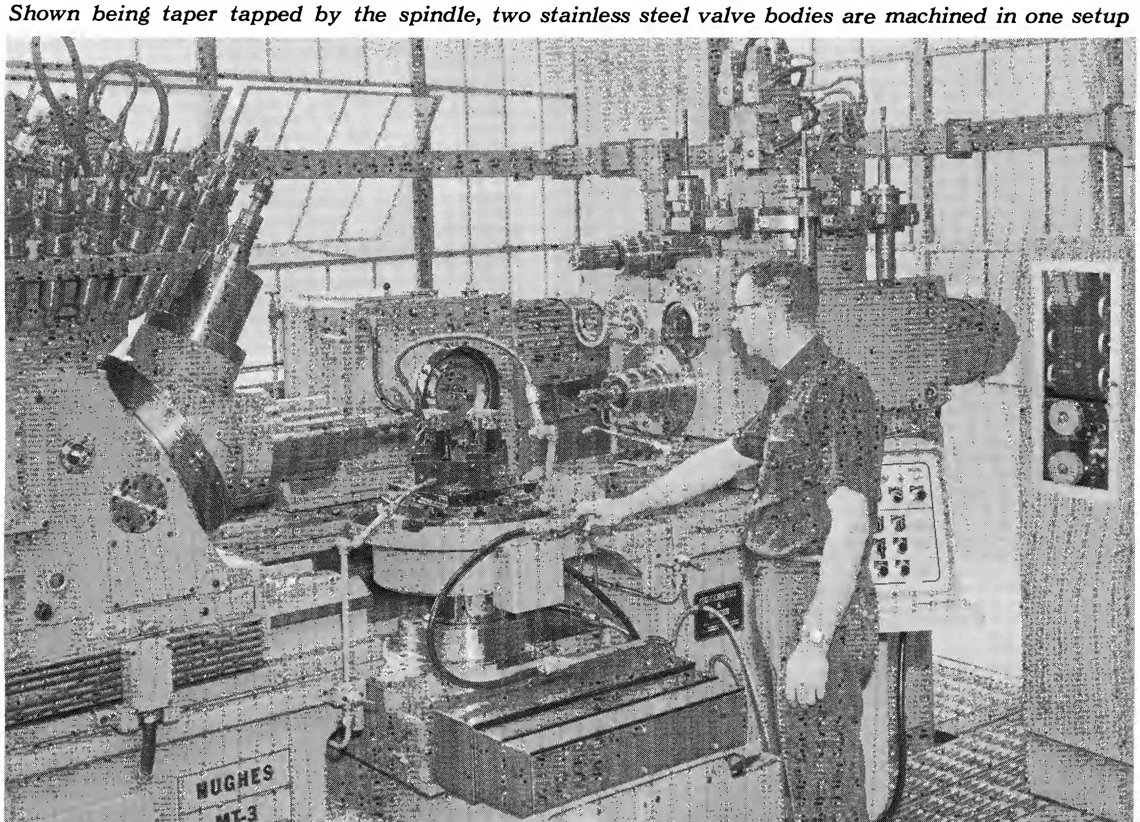
- *What advantages?*
- *Which parts?*
- *Which machine tool?*

First step of the investigating group was to select a number of parts with relatively low or short-run quantity requirements and screen them from the standpoint of their suitability for machining by numerically-controlled machines. This was followed by consultation with engineers and visits to companies building n/c equipment and systems, as well as to companies successfully using such equipment. During this early stage, one economic justification comparison was run in connection with a machine that seemed to measure up to requirements, but the decision not to purchase was made because the advantages over conventional machining were not especially impressive. It was during this early stage, however, that Aro's people became aware of the new Hughes MT-3 machining center while it was still on the drawing board and asked to be kept informed on its progress.

While most of the machines and systems that were looked into held considerable promise, and could machine Aro's selected parts if that were the sole consideration, the MT-3 machining center checked out to be the one best suited for Aro's particular situation. Its compact and rugged construction, coupled with fast tool changes and great versatility of tooling combinations, were important considerations in the decision. Hughes' long experience with n/c equipment and systems, dating back to 1954, and the fact that the MT-3 is a "second generation" machine of standardized modular construction incorporating the newest refinements also were influencing factors. (In a PRODUCTION Round Table in February, 1954, W. E. Brainard, then manager, general planning at Hughes, discussed the then-radically-new numerically-controlled machining line concept. In May 1958, PRODUCTION published "Automating for High Mix, Low Volume," a description of the first machining line built by Hughes to incorporate the concept.)

One of the first of the MT-3 machines built was installed by IBM's Endicott Division.

Shown being taper tapped by the spindle, two stainless steel valve bodies are machined in one setup



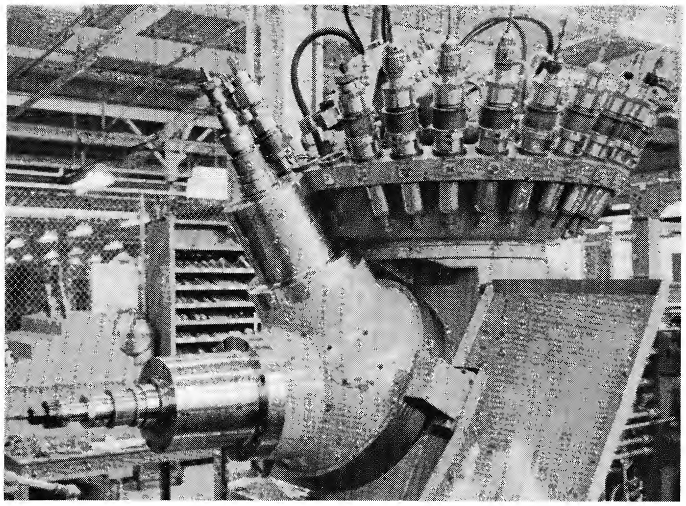
Through IBM's cooperation Aro learned a great deal about the intricacies of the machining system, its capabilities, personnel requirements, and some of the troubles that, without proper foresight, might be encountered.

Stage II—ECONOMIC JUSTIFICATION

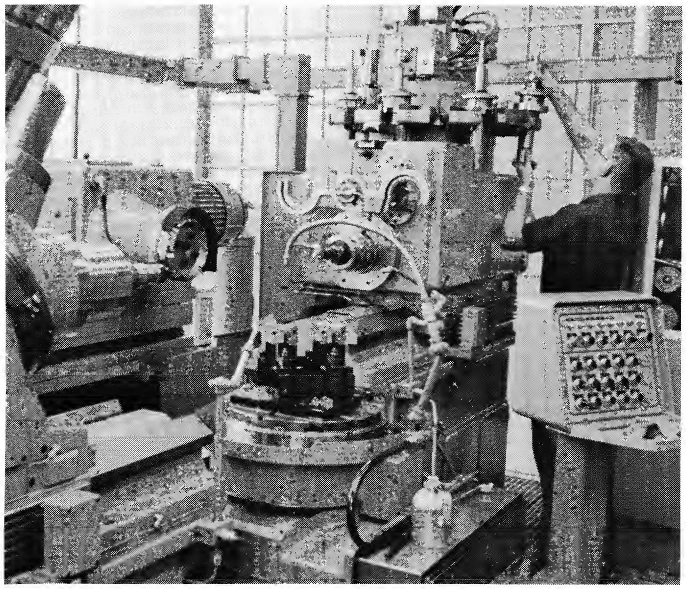
- *Total investment*
- *Setup time saving*
- *Labor cost saving*
- *Tooling cost saving*
- *Intangible benefits*

Aro selected a group of 15 parts for cost comparison purposes. At 90 per cent availability of the n/c machine, and on a two-shift basis (actually the machine now operates on a three-shift basis most of the time), it was found that the fully loaded n/c machine could process 5.6 groups of the 15 selected parts per year. Substantial savings could be made in production and set-up labor, and in tooling costs. It was calculated that set-up time with n/c would be only one-sixth of the time required with conventional equipment. The production labor requirement would be about one-half that needed for conventional operations. And tooling costs would be less than one-quarter the requirements with conventional equipment. Tool savings were claimed only for the first year because theoretically the machine will be fully loaded at the end of the first year. For subsequent years an annual saving of 20 per cent of the first year's saving was estimated for parts added or changed.

With a total expenditure of $230,840 (including $30,490 for such expense items as sales tax, tool holders, shipping, installation, and training of personnel) the payback period is less than five years. In addition to the calculated savings, there are very significant benefits which do not show up in this type of dollars and cents evaluation. For example, there is a reduction in lead time, or manufacturing cycle time normally needed to produce a finished new product; management control over manufacturing process is improved; in-process inventory and materials handling costs are reduced; and less inspection is required.



Above, the dual spindle arrangement on the universal machining head allows changing the tool in the angular spindle while the horizontal spindle is working. Below, preset tools are placed in the precision boring head's 14-station tool turret



Stage III—THE HUGHES MACHINE AND ITS USE

- *Three machining heads*
- *Simple fixtures*
- *Debugging*

Aro's numerically-controlled machining department at present contains the Hughes MT-3 machining center installed this past May, and a Cincinnati Cintimatic #3 installed a few months later.

The MT-3 combines three machining heads and a rotary-index work table which has vertical feed as well as cross feed. The Cintimatic

has a single vertical spindle and a tape-controlled work table which feeds horizontally in **X** and **Y** axes. Although the Cintimatic is capable (if given enough time) of performing any machine operation the MT-3 performs, it requires a different setup for each different plane of machining operations on the part.

The Hughes machining center is basically made up of three machining heads (left, rear, and right) clustered about a work table. The left hand head is for universal machining, and is equipped with a vertical-axis turret which contains a maximum of 30 tools, preset in spindle adapters. This head has two spindles, in a tipped V arrangement. When one of the two spindles is in a horizontal working position, the other is inclined upwardly in a "sleeper" position. Thus, automatic tool changes can take place in the sleeper spindle while the other spindle is working. When the working spindle completes its operation it indexes into the sleeper position, for a tool change, and the spindle that was in the sleeper position simultaneously indexes into the horizontal operating position. In addition to milling, drilling, boring, and reaming operations, the driven spindle is reversible to perform tapping operations. Twenty-eight spindle speeds are automatically provided by tape command, from 40 to 4,000 rpm.

The rear head is primarily for heavy face milling operations, and normally uses the same inserted-blade face mill cutter in all operations on a given part. Thus, there is no automatic tool changer associated with this head. Twenty-eight spindle speeds from 60 to 2,400 rpm are obtainable through pickoff gearing and high-low controls.

The right hand work head is a precision boring unit equipped with a turret containing up to 14 preset tools and an automatic tool changer which incorporates a device for radial registration of the changed tools. The tool changer selects the next tool to be used, removes it from the turret while the work head is operating, and holds it in a "ready" position for quick loading into the spindle when the tool in use completes its operation. This head customarily uses larger tools and is heavier and more rigid than the left hand head. In addition to precision boring, slab milling operations can be done with it because of its rigidity. Parts made out of stainless steel investment castings are examples of slab milled work. In this case a 2-in. dia. slab mill takes a pass over the top surface of the part, which later is drilled, taper reamed, and then threaded with ½-in. tapered pipe taps.

The work table is 18 in. in diameter and can be rotationally indexed to 16 angular positions selectively, under tape command or manual control. It feeds horizontally on a cross axis as well as vertically, at tape-controlled feed rates or in rapid traverse. The vertical movement is used for machining as well as for positioning to locate hole centers. In milling an undercut slot in a sand-cast aluminum part, for example, the spindle feeds a T-slot cutter into position beneath a wall of the casting and the table then feeds the part downwardly to the depth of the required cut, after which the table reverses to clear the part from the cutter.

Arrangement of the three work heads around the work table enables the workpiece to be presented to the different heads in an unlimited variety of sequences. One factor in determining the sequence, or whether a shift should be made from one head to another, is the time required for the automatic tool changes. Over-all, cycle time is saved because while one work head is cutting chips the next one to be used is automatically made ready.

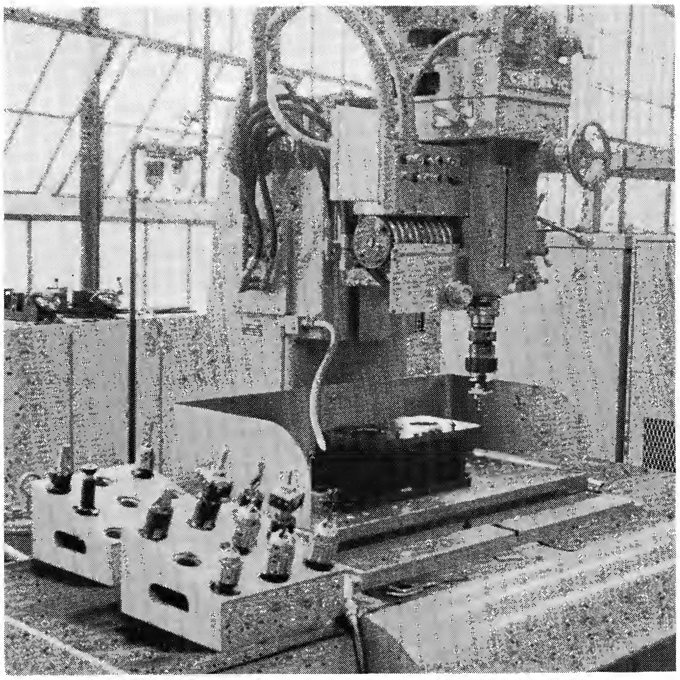
The machine tool's electronic control unit incorporates solid state control circuits and data handling techniques. Input is a standard 1-in. 8-track punched tape. A photoelectric reader operates at a speed of 200 rows a second, and a data handling time of 0.3 seconds per block eliminates the need for buffer storage equipment. Modular plug-in construction makes maintenance simple and quick.

There's a Danger of Over-Fixturing

Tooling savings usually are cited as the number one factor in any evaluation of n/c machining in relation to conventional machining. To a large extent, such savings are automatic, simply because of numbers. To machine a cast aluminum head for one of Aro's standard hoists, for example, requires some 18 operations. Conventionally, it requires chucking tools for boring operations, jigs for drilling and reaming, and milling fixtures. This same part, machined by n/c, requires only two setups, and two holding fixtures. The savings, obviously, are substantial.

In the face of such savings, there frequently is a tendency to over-fixture, particularly in cases where the n/c tools are designed and built by people experienced and normally occupied in designing and building tools for conventional machines. This dilutes some of the savings that n/c can make possible. Aro's experience along this line is indicative.

The first n/c fixture, for the cast hoist head, was designed and supplied by Hughes with the new machine. To the Aro engineers when they saw the design, "it had a spidery, almost flimsy, appearance that immediately gave the impression that it could not possibly hold the fussy location requirements specified for the part." The part, which is of a somewhat rounded shape, about 5 in. in the largest diameter, is set on two serrated pads in the fixture



Used for single-plane work, the tape controlled work table of a single spindle Cintimatic positions horizontally on X-Y axes

Preset in spindle adapters, tools are stored in the pockets of the tool change turrets, as well as in the special racks shown

and is held by two cone-point screws pushing it back against locators. A third screw holds the part from the top. The "spidery" nature of the fixture is necessary, of course, to expose all sides of the part, except the bottom, for machining.

This fixture was first used with misgivings; but such misgivings dissolved during the production of 600 parts. Ability to hold locations within tolerances was rated excellent. By making precise adjustments after preliminary boring, the operator could hold the required close bore tolerances with excellent reliability.

In general, the simpler the tooling the better. The best and least expensive type of holding device is an air vise with adapter pads specially designed to locate and position the part. Next best is an angle bracket with simple locators and clamps. But it has been Aro's experience, in connection with its first use of n/c equipment, that it is easy to lose sight of these fundamentals unless they are constantly stressed. Fixture designs for n/c bear watching, continuously, and preferably by someone who has an objective point of view.

A case in point involved a comparatively simple part for which the only holding tool called for by the programmer was an angle bracket support. The tool designer came up with a fixture operating on the pump-jig principle and of a solid design that left nothing to be desired from the standpoint of trouble-free operation and assurance that it was capable of producing a precision part. An expert in conventional tooling, however, pointed out that the design could easily be converted into a two-station fixture so that time could be saved by loading and unloading one station while a part was being machined in the other. The resulting fixture cost about \$900—not bad according to conventional standards—but too much fixture for the required lot of about 200 pieces. Rather than scrapping this fixture, and making one more in keeping with practical considerations, the company decided to keep it and use it as an object lesson of what to avoid in fixture design in the future.

In putting the machine through its acceptance tests after it had been installed, problems cropped up that had not occurred in the machining tests at the Hughes plant. While the malfunctions were individually minor, and generally were attributed to the movement of the machine during shipping, their accumulative effect became major, and it was a highly nervous period for all concerned. These troubles, however, were rather quickly licked, and since August the machine has been running with 10-12 per cent downtime. It is confidently expected that this figure in the future will come down to less than 5 per cent.

Although it's early to tell exactly how all actual costs will check against the justification estimates, preliminary costs are close to being "right on the button."

Stage IV—"INSURANCE"

- *N/C backs up n/c*

In addition to serving as a completely independent production machine, the Cintimatic #3 complements the Hughes machine in two respects: As a supplemental machining facility, and as a backup facility for emergency use in case the MT-3 is inoper-

ative for any extended period of time.

As a supplemental facility it performs single-plane operations on parts before they go into the Hughes machine. For example, in the case of a six-sided cube-shaped part, locating considerations limit the maximum number of sides that can be machined in one setup to five; so, in this instance, the sixth side can be machined economically in the Cintimatic, the MT-3 being used exclusively for multi-plane operations.

Because the Cintimatic could serve both as a backup and a supplemental facility, its economic justification analysis took this into account. Otherwise the same general justification procedure as used for the MT-3 was followed. It is common practice in the case of setting up to produce critical parts by radically new and sometimes unpredictable equipment to provide other methods in standby. And because the Cintimatic, in one way or another, can do any of the MT-3's operations, it eliminates the need for and the cost of such emergency stand-by equipment and tooling.

Final Note—PERSONNEL SELECTION

- *Promote from within*
- *Maintenance a key skill*
- *Operator qualifications*

The story of Aro's experience with n/c wouldn't be complete without an explanation of its personnel handling and training.

Aro is a growth company primarily because long-range management policies spur growth-mindedness among its people. A practice of promoting from within, and providing the training to make such promotion possible, encourages people to learn, to look ahead, and to welcome change as part of the growth pattern.

As n/c grew from a question, to a proposal, to a reality the seemingly drastic change in direction meant no more to the plant personnel than a to-be-expected step toward further growth. And they anticipated that the change to this new machining method would be accomplished entirely by themselves rather than by specialists from the outside. The integration of the new process into the over-all production scheme, therefore, was accomplished smoothly and in the company's tradition, that even major changes in direction are accomplished best by growth continuity rather than by crisis-producing crash programs.

The effect of n/c on Aro's personnel was no different from that of other major improvements undertaken by the company—it is simply one of many. The same thorough analysis and series of detailed studies has preceded a new system of automated handling which now is in the early stages. It will involve over-all modernization over a five-year period of stockrooms and in-plant transportation. Concurrently, another major improvement program involving management personnel has to do with training the management in the basics of electronic data processing equipment as a way of reducing detail work.

For its n/c installation, Aro selected its programming and maintenance people from the ranks, and these men received formal training at the Hughes plant, and additional training from the Hughes electronic specialist in charge of running the acceptance tests after the machine was installed in the Aro plant.

The Aro maintenance specialist concentrates only on n/c equipment. In connection with its electronics, he diagnoses the conditions and also performs whatever service is required. He also diagnoses hydraulic problems, but in this case repairs or adjustments are made by conventional machine repair people. This specialist's training at Hughes is considered vitally important to his ability to perform his job, but selecting the person with the required basic qualifications is considered equally important. Not all conventional machine repair men have the required background or interest in both electronics and hydraulics plus a general knowledge of machine repair and preventive maintenance, in Aro's opinion.

The operators also are selected carefully, but are trained in the Aro plant. The company operates under a job bidding system, and all bargaining unit members are eligible to bid for any new job opening up. When the need for n/c operators was posted, 37 bids were made and all of the applicants were screened carefully. Psychological tests were employed to determine suitability of attitudes and temperament. General screening considered such factors as job history, amount and variety of mechanical experience, education, and good job records that could be substantiated by their foremen. There was a preference for men under 40.

The training program started with three men, to equip one for each of the three shifts. Now, a total of six men have been trained, the additional three to operate the Cintimatic n/c machine that was acquired later.

Those chosen for operator training were selected on the basis of individual merit, seniority determining only which of the three shifts each will work. Although none of the men is a college graduate, most have had some schooling beyond high school, and, all are eligible and it is probable that some of them will advance to programmer positions when the growth that is expected takes place in the n/c machining department. ■